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Cost Analysis of Cochlear Implants in Deaf Children in The Netherlands

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Objective: The purpose of the study was to determine the costs of cochlear implants in children regarding the phases of selection, implantation, rehabilitation, and aftercare.

Study Design: This study was a prospective cost analysis paralleling a noncomparative observational study.

Setting: This study was conducted at a university hospital to evaluate cost data on selection and implantation and at an institute for the deaf to evaluate cost data on rehabilitation and aftercare.

Patients: The study group consisted of prelingual deaf children (mean age, 7 years; range, 4–11 years).

Intervention: A total of 106 deaf children were screened, of whom 20 received a cochlear implant.

Main Outcome Measures: This study concentrated on the cost of cochlear implants. Volumes of utilization of human resources and materials were registered during the 1-year follow-up. For the subsequent period, volumes were modeled on planned aftercare activities.

Results: Real total medical costs per implanted child were \$63,922; selection phase, \$7,747; implantation phase, \$30,442; rehabilitation phase, \$13,428; and aftercare, \$12,305. Nonmedical costs were \$1,839. Calculations were based on 1994 prices, and a time horizon of 5 years was used. The economic consequences of cochlear implants on educational needs were not taken into account because of the limited follow-up period. A sensitivity analysis of the rate of implanted children as part of the number of screened children showed a moderate impact on the total cost.

Conclusions: Compared to the results of cost analysis in other countries, the costs of the pediatric cochlear implants program in The Netherlands are relatively high. Most discrepancies can be explained by methodologic differences in the cost analyses.

Key Words: Cochlear implants—Deaf children—Cost analysis. *Am J Otol* 18:714–718, 1997.

Based on a series of studies showing safety and efficacy, multichannel cochlear implants were approved by the U.S. Food and Drug Administration for use in adults in 1984 and in children in 1990 (1). Until 1995, approximately 6,000 cochlear implant procedures had been undertaken worldwide (2). There is no comparable alternative medical treatment for total deafness. In many countries, policymakers are faced with the decision of whether to include cochlear implants in the basic medical benefit package. In the face of scarce resources, policymakers and healthcare purchasers are not only interested in the effects of certain healthcare interventions but also in the costs that are involved. Several studies have been published that report on the costs of cochlear implants, covering only Australia (2,3), the United Kingdom (4–6), and the United States (7,8). Some of these include analy-

ses of implantation programs for children. However, differences in healthcare settings in these countries influence the results of a cost analysis (9). Thus, applying the results in a specific policymaking context is difficult. This article describes the results of a cost analysis that was performed parallel to a clinical study of cochlear implants in children in The Netherlands. The results regarding the effectiveness of cochlear implants in children analyzed in this study are reported elsewhere (10–13).

METHODS

Between 1993 and 1996, 106 prelingual deaf children were screened as candidates for a cochlear implant, of whom 20 children were implanted. An extensive description of selection, inclusion, and exclusion criteria is reported elsewhere (10). The children received a multichannel cochlear implant, the Nucleus Mini System 22 with an MSP Processor (Cochlear Ltd, Lanecove, Australia). Their mean age was 7 years, 1 month (range, 3;11–11;11).

A societal perspective was used for the analysis, which implies that real costs of medical care were calculated instead of fixed reimbursement prices being used. In addition, nonmedical costs, such as patient and parent travel costs, were included in

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the analysis. The time horizon was 5 years. The cost analysis of selection, implantation, and rehabilitation during the first year was based on empirical data. Costs incurred during the remaining years were based on the planned aftercare. Costs of maintaining the external cochlear implant hardware during this period were estimated.

The data used for the cost analysis were obtained from two institutes involved in the project. For the cost analysis of selection and implantation, data from the University Hospital Nijmegen were used based on 106 and 20 children, respectively. In 1 of the 20 children, the cochlear implant was abandoned after 1 year because of inadequate hearing sensation levels. This child had a partial insertion due to total obliteration of the cochlea after meningitis. The data of the remaining 19 children were used for the cost analysis of rehabilitation and aftercare. These cost data were obtained from the Institute for the Deaf in Sint Michielsgestel.

The measurement of volumes

Volumes of utilization of human resources and materials were registered prospectively. The time spent by various personnel was recorded during the phases of selection, implantation, and rehabilitation. The use of facilities such as the operating room, recovery room, audiology center, and the special rehabilitation center was recorded in production entities such as number of hours of operating time, number of contacts with an audiologist, and days in the rehabilitation center. In addition, hospital days, outpatient visits, and return visits for rehabilitation were registered. Registration covered 1 year of follow-up after the implantation of each child. For the subsequent period, volumes were modeled on the basis of planned aftercare activities.

The measurement of prices

Calculations were based on 1994 prices. If prices were not available for this year, a price index was used to make the necessary corrections for inflation. Overhead costs of general departments such as hospital administration and personnel department were not included. Costs were analyzed in Dutch guilders and changed in U.S. dollars by using the 1994 mean exchange rate.

Prices of the different personnel categories involved (e.g., ear, nose, and throat [ENT] specialist, audiologist, psychologist, speech therapist) were based on the midpoint of the scale for each grade of professional involved, including scale-specific social security taxes. Expenses for other salary overheads, including holiday premiums and fringe benefits, were added (8% and 3%, respectively).

The costs of materials used were based on retail prices. Capital costs for the equipment were based on costs of depreciation, interest, and a surcharge for annual maintenance (8%) (14). Depreciation and interest were based on annuities of the initial capital outlay and the economic lifetime of the equipment involved. The annual annuity and maintenance costs were divided by the annual production numbers. For instance, the annual cost for general equipment in the operating room was divided by the annual number of operating hours. The annual cost of operating equipment specifically for cochlear implants was divided by the number of implants performed annually. The cost of using an accommodation was added in proportion to the time that the accommodation was used. Energy costs and cleaning costs per square meter were calculated on the basis of actual space used.

The price of a hospital day was obtained by dividing the annual costs for nursing staff, materials used, meals, and other hotel costs by the number of hospital days realized in the ENT department. The price per hour of the ENT outpatient department was determined on the same basis. Diagnostic tests such as

computed tomographic scan, magnetic resonance imaging, and electrocochleography/electrical auditory brainstem response test (EBER) were valued according to the appropriate reimbursement prices. Extensive cost analyses on these diagnostic tests were not performed because these charges were an approximation of the integral price (14).

For rehabilitation, a special cochlear implantation center was available, which was used solely for this purpose. The annual costs of this facility were calculated on an integral basis, including annual costs of the building, equipment, and power. These annual costs were divided by the number of patients who entered the rehabilitation phase annually.

Nonmedical costs included the travel costs of the children and parents. Travel distances to the institutions were estimated with a route-planning program using postal codes. In accordance with Dutch guidelines for cost analysis in healthcare, a price of \$0.22/km was used (14). The costs of aftercare taking place after the year of implantation were discounted 5% (15).

Sensitivity analysis

To assess the impact of certain variables on the robustness of the conclusions, a sensitivity analysis was performed. During the clinical study, 20 (19%) of 106 children were selected to have a cochlear implant. This rate of implanted children as part of the number of screened children varied between 9% and 29% as possibly being important to the estimated total costs of cochlear implant per child.

RESULTS

Selection costs

One hundred six deaf children entered the selection phase for a cochlear implant. The application and intake of each of these children consumed relatively little time of the cochlear implant team members. Surcharges for accommodation and the cost of administrative materials were added, which resulted in \$667 per child and \$70,736 in total.

The screening resulted in 20 candidates who were considered suitable for a cochlear implant. These children were subjected to audiology, psychological, and medical tests, and they underwent a computed tomographic scan to see whether the cochlea was suitable for insertion of the electrode arrays. For seven of the children, general anesthesia was needed to perform the computed tomographic scan, which required a 1-day stay in the hospital. More costly were tests such as magnetic resonance imaging (sometimes with the patient requiring general anesthesia and, thus, a 1-day hospital stay) and electrocochleography/electrical auditory brainstem response test (EBER). The latter was done operatively with the patient under general anesthesia requiring a 3-day hospital stay. However, these tests were conducted on only five children. The total cost for all children for audiology, psychological, and medical testing was \$51,277.

In addition to these child-specific activities, the costs of the team involved in this selection phase were analyzed. These activities consisted mainly of team meetings to discuss the candidacy of the children for a cochlear implant. Along with travel costs, the actual time spent by the team members was calculated, resulting in a total cost of \$32,939.

Thus, the total cost involved in the selection procedures was \$154,952. These costs were ascribed to the 20 implanted children, which resulted in a selection cost of \$7,747 per implanted child.

Implantation costs

The main cost of the implantation phase was the cost for the cochlear implant hardware. Although the internal hardware should last a lifetime and the external hardware should last for at least 8 years, no depreciation calculations were performed. The price of the hardware was considered a cost only in the year of implantation because the hardware is used solely for the benefit of one patient. At the time of the study, the price for the hardware was \$25,216. The cost for small materials used, including the cost of sterilization, was \$1,140 per operation. Capital costs for medical equipment were calculated as a surcharge for an implant operation. Per-operation costs were \$32 for implant-specific equipment, \$58 for ENT-specific equipment, and \$162 for general equipment. Including overhead costs of the operating room (e.g., cleaning, housing), the total per-operation overhead cost was \$322.

The costs of personnel were calculated based on the amount of time spent in the operating room, which resulted in \$1,240 per operation. Total implantation cost was \$27,917 per child.

The cost for a 1-day hospital stay was \$369. Mean stay in the hospital was 6.6 days. After a patient had been discharged, an outpatient visit was planned to check the healing of the operation wound and overall condition of the patient. This visit lasted 45 minutes, costing the ENT specialist time and a surcharge for accommodation (total \$88). The cost for the hospital stay and outpatient clinic visit was \$2,525 per patient. Together with the cost of the operation itself, the total cost of the implantation was \$30,442 per child.

Rehabilitation costs

All activities in the rehabilitation phase took place in the cochlear implant rehabilitation center of the Institute for the Deaf in Sint Michielsgestel. Infrastructure costs of \$2,689 per rehabilitated person were calculated. The remaining costs were calculated on a variable basis. In addition to the institute's audiologist, audiology assistant, speech pathologist, and speech therapist, the child's teacher and the school speech therapist also were involved in the rehabilitation phase.

The rehabilitation phase was divided into several stages. A few weeks after implantation, the external cochlear implant hardware had to be fitted. The audiologist spent 28 hours, the audiologic assistant 4 hours, and the speech therapist 20 hours in this hardware-fitting phase. This time spent cost \$1,690 per child. After the fitting, the actual rehabilitation started. A child would stay with one or both parents in the center twice a day for 5 days. Each day, several sessions were performed with a child. For efficiency reasons, two children who were implanted stayed in the center at the same time. Analyses of

time spent by the team members, travel time included, resulted in 6 hours of audiologist time, 201 hours of speech therapist time, and 16 hours of speech pathologist and school speech therapist time. For each child who was rehabilitated, estimated costs were \$7,397. After this period of intensive rehabilitation, the child's progress was assessed regularly. This was done either at the cochlear implant rehabilitation center or at the regular school. These assessments occurred monthly during the first 3 months and once every 6 weeks during the remaining months of the first year. This assessment period cost \$1,652 per child and included only the cost for personnel. The total cost of the rehabilitation phase was \$13,428 per child.

Long-term care costs

During the second year after implantation, 4 assessment and tuning days were planned; in the third year, 2 days were planned, and in the fourth and fifth years, 1 day each was planned. Each visit consisted of several hours of contact between the patient and the different team members. The total cost for a day was \$846. In addition, each child received a fixed number of hours of speech and hearing therapy annually, costing \$594 per child per year. The different discounted costs per year totaled \$8,287 per child for this 4-year postoperative period.

In addition to the cost of the aftercare days, maintenance of the cochlear implant hardware was estimated. The external hardware requires periodic maintenance and has more breakdowns in children than in adults. For this reason, one spare processor was needed per eight children. Additionally, the infrastructure for maintenance and small replacement materials was needed. Estimated per-year costs were \$1,133 per child. The discounted maintenance costs for the 5 years were \$4,018 per child.

Adding all annual aftercare costs and using a discount rate of 5%, the total cost for the aftercare from the second through the fifth years was \$12,305 per child.

Nonmedical costs

The nonmedical cost related to the cochlear implant procedure was the travel costs of the parents accompanying the child. The children came from all over The Netherlands, with a mean distance of 133 km, to the University Hospital and 139 km to the Institute for the Deaf. The number of visits multiplied by the travel costs resulted in the mean travel costs for the whole 5-year period. Like the selection costs, the travel costs of the children who entered the selection phase were ascribed to the children finally implanted. Using a 5% discount rate for the costs after the first year, the travel costs were \$2,086 per implanted child.

Overall result

The overall result of the cost analysis of cochlear implants in children is presented in Table 1. The total medical costs per implanted child are \$63,922, given the baseline rate of implanted children as part of the number of screened children of 19%. Varying this rate in a sensitivity analysis between 9% and 29% results in total costs per child of \$70,258 and \$62,083, respectively, which

TABLE 1. *Costs (in US dollars) of cochlear implants in children*

	Cost per child	Number of children	Total cost	Cost per implanted child
Selection				
Application and intake	667	106	70,736	
Psychological and medical test	2,564	20	51,272	
Team activities			32,939	
				7,747
Implantation				
Hardware	25,216			
Operation	2,702			
Hospital days	2,436			
Outpatient visit	88			
				30,442
Rehabilitation				
Regulating hardware	1,690			
Rehabilitation	7,397			
Assessment	1,652			
Overhead	2,689			
				13,428
Long-term care (until 5th year)				
Contact days	8,287			
Maintenance	4,018			
				12,305
Total medical cost per implanted child				63,922
Nonmedical cost per child				2,086

means that the rate has only a moderate impact on the total cost per implanted child.

DISCUSSION

The results of our cost analysis of cochlear implants in children primarily are useful for reimbursement issues of policymakers. No comparison has been made with another facility because the clinical study was a noncomparative observational one. For this reason, the concept of opportunity costs, such as financial comparison with other facilities for the deaf, has not been applied.

The cost related to the educational needs of the children was not part of the cost analysis, because of the limited follow-up period. However, Hutton et al. (6) suggested that the impact of cochlear implants on education is a key factor in the evaluation of cochlear implants in children. Their study presented considerable lifetime savings on costs of education (£51,265, approximately \$72,494), but as the authors state, these results must be treated with caution. Other longer term financial benefits might occur when persons with a cochlear implant are employed, therefore contributing to the tax base rather than being dependent on social security (16). Concerning cochlear implants in adults, an increase in income after implantation was measured (8). However, as long as the impact of cochlear implants on the educational setting of the children is not investigated properly, it will remain difficult to predict any changes in the cost of education and the children's eventual employment status (17).

The societal viewpoint of the analysis requires incorporating more relevant cost categories in our analysis. Considerable amounts of time were required of the parents during

the selection and implementation phases as well as during the rehabilitation and as in the 4-year aftercare period. The indirect costs involved (lost labor time) were not part of our analysis because the relevant data were not available.

During our study, no major complications in the 19 children were faced because of the cochlear implants. Major complications could cause our calculations to be seriously underestimated. In the literature, few complications have been reported (18). Removal of the implant was only necessary in 0.6–1% of the cases. In addition, anesthetic complications, flap-related problems, and electrode placement problems might occur. Of course, such an event would increase costs for treatment for the specific patient. However, regarding the small chance of complications, the mean cost of cochlear implants in children does not increase significantly. The results of sensitivity analyses performed in published studies showed that the influence of these probabilities was negligible on the ratio between costs and quality-adjusted life-years gained (4,7).

As our study confirms, the price of the implant hardware is a large part of the total cost of a cochlear implant procedure. Other studies show that the ratio between cost and effect is highly sensitive to this price. The price might decrease in the future (4). However, no considerable change in the price of the cochlear implant hardware currently is expected (16).

The results of this study are based on the Dutch medical procedures, which influence the costs, especially those concerning the selection and rehabilitation phases. Changes in the procedures might change the costs involved; for instance, hospitalization for testing or imaging studies, which were performed in one third of the children who were implanted, may be avoided in the future. In addition to this, economies of scale, that is, the

number of implants performed in a center per year that might vary among different countries, influence the surcharges of fixed costs.

Comparison of results

Compared to the results of cost analyses in other countries, the cost of the pediatric cochlear implants program in The Netherlands is relatively high. Most discrepancies, however, can be explained by methodologic differences.

In a decision-modeling approach, costs of cochlear implantation in the United Kingdom were described (6). The estimated cost of selection was £790 (approximately \$1,090) and the cost of implantation was £15,522 (\$21,868); the rehabilitation phase was estimated to cost only £900 in the first year and £3,750 in subsequent years (\$6,571 in total) until age 16. Although the costs were categorized in the same phases as in our study, a straightforward comparison of the results is difficult because no information was provided concerning the sources for the cost data, overhead, and accommodation costs, and the year of the prices. In addition to this, the total cost of the selection phase was not ascribed to the children who were implanted. As the authors state, the results of their exploratory work must be treated with caution because the analysis incorporates a large number of assumptions.

The studies by Lea (3) and Lea and Hailey (2) mention costs for selection, operation, implant hardware (\$17,030), and rehabilitation for prelingual deaf children totaling \$36,630. However, these costs were based on reimbursement prices in Australia instead of real costs, which invalidates a comparison with the results of our study. In addition, relatively low prices for the hardware were used in the calculations.

The estimated costs mentioned by Wyatt et al. (7) were based on a decision-analysis model concerning postlingual adults. Because of the essential differences in the selection and rehabilitation phases, only the cost of the implantation phase can be compared with that of our results. The total cost of implantation consisted of the implant hardware costs (\$19,383) and the operating costs (\$12,227). It is not clear whether these figures were based on reimbursement prices or on real costs. However, the operating costs in this study were considerably higher than those in the current study.

In the studies by Davis et al. (5) and Harris et al. (8), only the cost of the implant hardware and, in the latter study, the cost of the operation were considered. The basis for these estimations is not clear. Considering our results, these studies seem to underestimate the costs that actually were involved in cochlear implants.

The above-mentioned studies all involve cochlear implants for adults. Because costs of cochlear implants in adults can not be translated to those in children, the study by Summerfield and Marshall (4) is relevant. In this study, the costs of a pediatric implant program in the United Kingdom are analyzed. Total costs at the end of

the first year were £24,250 (approximately \$34,266). Taking into account the much lower price for the implant hardware used in their estimates and the general differences in the pediatric programs, the result of Summerfield and Marshall is in line with that of our calculations.

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